# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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## STATIC AND IMPACT STRENGTHS OF RIVETED AND SPOT-WELDED BEAMS OF ALCLAD 14S-T6, ALCLAD 75S-T6, AND VARIOUS TEMPERS OF ALCLAD 24S ALUMINUM ALLOY

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# STATIC AND IMPACT STRENGTHS OF RIVETED AND SPOT-WELDED BEAMS OF ALCLAD 14S-T6, ALCLAD 75S-T6, AND VARIOUS TEMPERS OF ALCLAD 24S ALUMINUM ALLOY

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## SUMMARY

Static and impact tests were made on riveted and spot-welded beams of various high-strength aluminum alloys. The beams of this investigation were spot-welded before present aircraft specifications for structural welding became effective. It is evident from radiographic analyses that the soundness of the spot welds of this investigation does not meet these present specifications. In interpreting results, therefore, the limitations should be considered.

For static loads on riveted beams, the values of modulus of failure were about the same as tensile strengths for all the alloys except one; for static loads on spot-welded beams, the values of modulus of failure were lower than the tensile strengths for all the alloys.

In general, beams of highest-strength materials had the greatest resistance to impact. The height of drop producing failure of the spot-welded beams averaged about 70 percent of that producing failure of the riveted beams.

No direct relationship seems to exist between the toughness value of the material as determined from the tensile properties and relative ability to resist impact of the material in the form of a riveted or welded structure. Aging of beams after assembly is not advantageous and probably undesirable, at least for spot-welded beams, from the standpoint of static and impact strength.

## INTRODUCTION

The increased use in aircraft construction of higher-strength aluminum alloys such as 75S-T6 and the various tempers of 24S obtained by artificial aging has made evident the need for information concerning the behavior of structures of such alloys under static and impact loading. It seemed desirable to study the performance of riveted and spot-welded connections in a structural member subjected to static and impact beam tests in which the components of the built-up member bend as a unit and cause the connections to undergo stresses of a different type from those encountered in tests of simple joints. Of particular interest was the comparison of the resistance to tensile rupture of the various alloys when used in riveted and spot-welded construction. Consequently, the beams were proportioned so as to ensure failure in the tension cover plate. This required making the compression cover plate of sufficient thickness to prevent buckling and the web of sufficient stiffness to preclude buckling due to shear or bending.

In order that an investigation could be made of any possible beneficial effects resulting from relief of internal strains set up during assembly, particularly during the spot-welding operation, beams which were fabricated from Alclad 24S-T3 aluminum alloy and aged to the -T81 condition after assembly were included for tests.

The object of this investigation was to determine the comparative strengths under static and impact loading of built-up riveted and spot-welded beams of Alclad 14S-T6, Alclad 75S-T6, Alclad 24S-T3, Alclad 24S-T36, Alclad 24S-T81, Alclad 24S-T86, and Alclad 24S-T3 aluminum alloy artificially aged to -T81 after assembly.

This work was done by the Aluminum Company of America and has been made available to the NACA for publication because of its general interest.

## SPECIMENS AND MATERIAL

The type of specimen used for the static and impact beam tests is shown in figure 1. The top cover plates of all the beams were 1/4-inch Alclad 75S-T6 plate and the back-up strips, used to prevent the flanges from buckling between rivets, were 1/8-inch 24S-T4 rolled rectangular bar. The spacer blocks in all the beams were 1/2-inch Alclad 24S-T4 plate. The connections in the top cover plates of all the beams were made by means of 1/4- by 3/4-inch A17S-T3 buttonhead rivets. In 28 of the beams the bottom cover plate was spot-welded to the channels, and in the other 28 the connection was made by means of riveting. Four beams with riveted bottom-cover-plate connections and four with spot-welded bottom-cover-plate connections were made of each of the following alloys and tempers of 0.064-inch-thick channels and cover plates: Alclad 14S-T6, Alclad 75S-T6, Alclad 24S-T3, Alclad 24S-T36, Alclad 24S-T81, Alclad 24S-T86, and Alclad 24S-T3 aged to -T81 after assembly. The specimens which were aged to -T81 after assembly were aged before the Alclad 75S-T6 top cover plate was attached because the prolonged aging (11 hr at 375° F) would have appreciably reduced the yield strength of the Alclad 75S-T6. The bottom cover plates were attached to the flanges by means of fifty-five 1/8-inch-diameter 24S-T31 rivets or thirty-seven 9/32-inch-diameter spot welds in each of the two flanges. The over-all length of the beams was 56 inches. Average measurements of five beams chosen at random showed the greatest deviation of any dimension from nominal to be $1\frac{1}{2}$ percent, which is well within commercial tolerance.

All the work of fabricating the beams, including the forming of the channels and the aging of the Alclad 24S-T3 to -T81 after assembly, was done by the Jobbing Division of the New Kensington Works. The 1/4-inch A17S-T3 rivets were driven cold in 0.257-inch holes and the 1/8-inch 24S-T31 rivets were driven cold in the freshly quenched condition after having been heat-treated 20 minutes at 920° F followed by a cold-water quench. The 1/8-inch rivets were driven in 0.1285-inch holes. All rivets were driven with flat heads having diameters $1\frac{1}{2}$ times the shank diameters. The rivet holes were drilled with the parts of the beams assembled.

In addition to the beams, spot-welded panels of the type shown in figure 2 were prepared of each alloy. These panels were for the purpose of determining the strength of simple spot-welded joints. Specimens of the type shown in figure 3 were used for the determination of the static shear strength of the 1/8-inch 24S-T31 rivets. The sheet material used in these specimens was 0.064-inch Alclad 24S-T3.

## PROCEDURE

Mechanical-property determinations were made of the various materials used in the construction of the beams by using standard sheet-type tensile specimens. Tensile yield strengths (0.2 percent permanent set) were determined by means of a Templin electrical extensometer. The properties were determined in the with-grain direction.

Each of the spot-welded panels, of the type shown in figure 2, was cut into specimens approximately 1 inch wide with a spot centered in each specimen and these were tested to determine the shear strength of the spot welds. These tests, the mechanical-property tests, and those of the riveted specimens of the type shown in figure 3 were made in a 20,000-pound-capacity Amsler Universal Testing Machine,[1] using Templin self-alining grips for all tensile tests.

The spot-welded panels and beams were given radiographic examinations.

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[1]Type 10, SZBDA.

## Static Beam Tests

The static beam tests were made in a 40,000-pound-capacity Amsler Universal Testing Machine,[2] using the test setup shown in figure 4. The beams were simply supported on a 4-foot span. The steel block which was designed as a striking block for the impact beam tests was used to distribute the load in the static beam tests. This block was about $2\frac{1}{2}$ by 3 by 4 inches and was crowned in order that the load would continue to be distributed evenly as the beam deflected. The block was fastened to each beam as shown in figure 1. Similarly, the plates designed to distribute the end reactions in the impact beam tests were used for the same purpose in the static beam tests. These plates were counterbored so as to accommodate the rivet heads in order to obtain intimate contact with the cover plates of the beams.

Loads were applied in 250-pound increments to failure. The deflections were measured by means of a 1/1000-inch-dial gage placed between the auxiliary beam of the testing machine and the center of the bottom cover plate of the specimen. It is recognized that the steel auxiliary beam deflects slightly under load; however, the stiffness of the auxiliary beam is so great relative to the aluminum-alloy beams being tested that the slight deflection of the auxiliary beam may be neglected. Care was taken to prevent scratching or penetration of the cover plate by the point of the dial gage. This was accomplished by the use of a cardboard centering device which was glued to the bottom cover plate and which served to hold the point of the dial against the center of the beam without the necessity of using a prick punch mark. Load-deflection curves were obtained by means of an automatic autographic device on the testing machine (Amsler diagrams). In addition to deflection measurements, strain measurements were made on three of the beams by means of SR-4 electric strain gages. Static beam tests were made of two riveted beams and two spot-welded beams of each alloy and temper.

## Impact Beam Tests

The setup for the impact beam tests was as shown in figure 5. The beam was simply supported on a 4-foot span. The striking block and end fixtures were used as described previously. The end fixtures rested on steel rails which were clamped to 30-inch steel CB sections. Excessive lateral or vertical movements of the ends of the beams were prevented by means of steel angles bolted to the CB sections. Longitudinal movements of the beams were controlled by means of steel plates which were bolted to one of the end fixtures and which bore against the steel rail. Blows were applied by dropping a 250-pound tup on the striking block which was affixed to the center of the beam. The height of drop was

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[1]Type 20, SZBDA.

increased by 1/2-inch increments until failure occurred. The amount of permanent set was measured after each drop by means of a dial gage with suitable extensions placed between the center of the bottom cover plate of the beam and a plate on the base of the impact tower. As in the static beam tests, care was taken to prevent scratching or penetration of the bottom cover plate by the point of the dial. Impact beam tests were made of two riveted and two spot-welded beams of each alloy and temper, except Alclad 24S-T81 and Alclad 24S-T86, in each of which only one riveted beam was available.

## RESULTS AND DISCUSSION

### Mechanical Properties

Results of the mechanical-property determinations of the materials used in the beams are given in table I. Included for comparison are design mechanical properties (taken from reference 1). Also shown in table I are "toughness" values which were chosen arbitrarily for comparisons to be made later. It is seen that, except for Alclad 24S-T3 aged to -T81 after assembly, the materials used in the beams exhibited mechanical properties greater in magnitude than the design mechanical properties. The most reasonable explanation for the fact that the Alclad 24S-T81 and Alclad 24S-T3 aged to -T81 after assembly exhibited tensile strengths lower than Alclad 24S-T3 seems to be that, considering the higher than average amount of cold work in the Alclad 24S-T3 material (as evidenced by the mechanical properties, particularly the yield strength), it is probable that the commercial aging treatments resulted in slight overaging with an attendant lowering of tensile strength.

### Shear Strength of Rivets and Spot Welds

The results of the static shear tests of the spot welds and rivets are shown in table II. Included for comparison are values of design shear load per spot weld or rivet and design shear strength of driven rivets (taken from reference 1). It is seen that the strength per spot weld or rivet exceeds the design load except in the case of Alclad 14S-T6 spot-welded material where the minimum load per spot obtained was less than the design load, although the average value of load per spot weld was considerably greater than the design load value.

The spot weld which exhibited the least value of shear load was one which was described as "sound" according to radiographic analyses of the panels, the results of which are shown in table III. Also included in Table III are the average values of ultimate shear load per spot which are summarized in table II. The values shown in table III are the average values per panel, some of which contained two, and some of which contained three spots. The wide range of shear loads encountered cannot be satisfactorily explained by the presence or absence in the welds of cracks, porosity, or expulsion. Table II shows that the spot-welded panels of Alclad 75S-T6 not only proved to be definitely superior to those of other alloys in point of ultimate load per spot, but also exhibited a pronounced advantage over the panels of the other alloys from the standpoint of consistency. The spot welds in the Alclad 14S-T6 panels, all of which radiographic examination showed to be sound, developed the lowest average strength and the greatest deviation from average of all the alloys.

The significance of the results of the shear tests of the spot-welded panels in relation to the beam tests is that, even though the welds exhibited a considerable number of defects in radiographic examination (see table IV), the welds could probably develop static shear strengths greater than design values.

## Static Beam Tests

The results of the static beam tests are given in table V and in figures 6 to 10. Figure 6 shows some typical failures of riveted beams, and figure 7 some typical failures of spot-welded beams. All the failures occurred through the rivet holes or through the center of the spot welds, the failure being of the material rather than by shearing of the rivets or spot welds. The appearance of the fracture in every case was that of the shear-type failure in which the plane of the fracture is at an angle of about 45° with the plane of the sheet. It is logical, therefore, that the beams should have sustained ultimate loads commensurate with the tensile strength of the materials from which the beams were made. Failure in all the beams occurred in the region of theoretical maximum stress, at the middle of the span, that is, from rivets 26 to 30 or spot welds 18 to 20. Table VI contains the radiographic analyses of the spot welds through which failure occurred.

The load-strain curves of the three riveted beams to which SR-4 electric strain gages were applied are shown in figure 8. The dashed lines in figure 8 represent the computed elastic strains based on the bending moment at a point in the bottom cover plate opposite the edge of the bearing block. The strains were measured by means of the SR-4 strain gages at the same point. The computed strains shown were based on both the primary and secondary modulus of elasticity for Alclad 24S-T36 and Alclad 75S-T6. The value of moment of inertia used in these calculations was based on nominal dimensions and on gross area of the flanges. It is seen that the measured strains agree quite well with the computed strains based on the primary modulus and to but a slightly lesser degree with the strains based on the secondary modulus, indicating that these built-up beams acted as solid beams of similar cross section would be expected to behave.

The load-deflection curves of the static tests, based on dial-gage measurements, are shown in figure 9. The dashed lines represent computed deflections. The computed deflections were based on the secondary modulus of elasticity except, of course, for Alclad 14S-T6 in which case no distinction is made between primary and secondary modulus. A comparison of the difference between the computed and measured deflection (elastic) of the beams shows that on the average the measured deflection of the riveted beams was about 12 percent higher than the computed deflection, and in the case of the spot-welded beams the measured deflection was about 10 percent higher than the computed deflection. This indicates that the spot-welded beams were slightly stiffer than the riveted beams. The Alclad 75S-T6 beams showed the least difference between measured and computed deflections, $5\frac{1}{2}$ percent for the riveted beams and $6\frac{1}{2}$ percent for the spot-welded beams. For the riveted beams, the Alclad 24S-T3 showed the greatest difference, 17 percent, and for the spot-welded beams Alclad 14S-T6 showed the greatest difference, 16 percent. These differences would have been greater had the primary modulus been used as a basis for the computed deflection.

To facilitate comparisons, some of the results contained in table V are shown graphically in figure 10, which shows the moduli of failure of the riveted and spot-welded beams compared to the tensile strength of the material from which the beams were made. Both average and individual values of modulus of failure are shown. The alloys are arranged in order of increasing design allowable tensile strength.

The values of ultimate load or modulus of failure in the static tests agree fairly well for the two beams of each alloy and temper and type of connection. As would be expected, the difference between these values for the riveted beams was less than for the spot-welded beams. The Alclad 24S-T81 beams exhibited the greatest difference between the average and individual values for both the riveted and spot-welded beams, the difference being but $3\frac{1}{2}$ percent for the riveted and about $14\frac{1}{2}$ percent for the spot-welded beams. Of all the beams, the Alclad 24S-T3 aged to -T81 after assembly showed the most consistent results between the two beams of each type of connection, the variation from average being less than 1 percent.

For each alloy and temper the average ultimate load or modulus of failure of the riveted beams exceeded that of the spot-welded beams. On the average the difference between the ultimate loads of the riveted and spot-welded beams was about 12 percent. The least difference was for beams of Alclad 14S-T6, about 7 percent. The greatest difference was for beams of Alclad 24S-T3 aged to -T81 after assembly, about 22 percent. Beams of Alclad 24S-T81 showed a difference of about $13\frac{1}{2}$ percent. The significance of the greater difference in the case of Alclad 24S-T3 aged to -T81 after assembly would seem to be that, from the strength standpoint, no benefit results from aging to -T81 after assembly and, in fact, it may be harmful. There seemed to be no definite relationship between the magnitude of the difference between the ultimate loads of the riveted and spot-welded beams and the strength or the ductility of the material from which the beams were made.

The values of ultimate load of the riveted and spot-welded beams were in about the same sequence as the values of ultimate tensile strength. This trend is shown graphically in figure 10. The following table is based on the average values shown in figure 10 and contains the ratios in percent of modulus of failure to tensile strength.

| Alloy and temper | $\frac{\text{Modulus of failure}}{\text{Tensile strength}}$ (percent) | |
|---|---|---|
| | Riveted beams | Spot-welded beams |
| Alclad 24S-T3 | 88 | 75 |
| Alclad 14S-T6 | 96 | 90 |
| Alclad 24S-T81 | 100 | 87 |
| Alclad 24S-T3 aged to -T81 after assembly | 98 | 76 |
| Alclad 24S-T36 | 102 | 94 |
| Alclad 24S-T86 | 100 | 90 |
| Alclad 75S-T6 | 101 | 90 |

For the riveted beams, only the Alclad 24S-T3 showed a modulus of failure significantly different from the tensile strength - about 12 percent lower. Of all the others, the greatest variation was for Alclad 14S-T6 - about 4 percent lower. These findings are consistent with the results of tests of sheet specimens with open holes. (Refer to reference 2.) In the spot-welded beams, those of Alclad 24S-T3 and Alclad 24S-T3 aged to -T81 after assembly showed a modulus of failure about 25 percent lower than the tensile strength, while all others showed a reduction of about 10 percent. The ratio of modulus of failure to tensile strength was higher in the higher-strength alloys, which is contrary to the usual expectation.

The total deflections at rupture shown in table V were measured from the Amsler diagrams. It is seen that the riveted beams showed greater deflections at rupture than the spot-welded beams. According to these deflections, the riveted beams fall in two groups: the Alclad 24S-T3, the Alclad 24S-T3 aged to -T81 after assembly, and the Alclad 75S-T6 exhibiting the greater deflections - about 1.3 inches, all others having deflections about 15 percent lower. The deflections at rupture of the Alclad 24S-T3 aged to -T81 after assembly and Alclad 24S-T36 beams were not consistent with the elongation of the materials, the former showing a deflection in the high group although the elongation of the material was 7.1 percent, the latter showing a deflection in the low group although the elongation was 15.1 percent.

Of the spot-welded beams, those of Alclad 75S-T6 showed the greatest deflection - about 1.0 inch. Beams of Alclad 24S-T3, Alclad 24S-T31, and Alclad 24S-T3 aged to -T81 after assembly showed the lowest deflection - an average of about 0.7 inch. The low deflection of the Alclad 24S-T3 beams was not consistent with the elongation, which was 19.8 percent.

## Impact Beam Tests

Results of the impact beam tests are shown in table V and figures 11 to 14. All the beams failed through the rivet holes or through the center of the spot welds in the same manner as in the static tests. The failures were in the sheet and not by shearing of the rivets or spots. Figure 11 shows some typical failures of the riveted beams and figure 12 of the spot-welded beams. Theoretically the region of maximum stress was from rivets 26 to 30 and spot welds 18 to 20, counting from either end of the specimen. All the beams failed either in this region or at the rivets or spots immediately adjacent.

The curves of height of drop against permanent set for the impact tests are shown in figure 13. These indicate the extent to which the various beams were deformed prior to failure. No measurements of total deflection were taken on the impact tests because of the nature of the test and consequently there is no basis for comparison to the values of total deflection at rupture in the static tests (table V).

In figure 14 are shown values of tensile strength, toughness value, and maximum height of drop, plotted so as to facilitate comparisons.

The toughness values shown were arbitrarily computed from the mechanical properties of the material (table I) as the average of the tensile strength and the yield strength, multiplied by the elongation. Individual and average values of maximum height of drop are shown.

Where two riveted beams of each alloy were tested, the height of drop causing failure was about the same for each of the two beams. The greatest difference from the average value, about 4 percent, was in the case of Alclad 75S-T6 beams. The spot-welded beams did not prove to be so consistent, the greatest difference being about 27 percent in the case of beams of Alclad 24S-T3 aged to -T81 after assembly. There was considerable variation in the ratios of height of drop causing failure in the spot-welded beams to that in the riveted beams of a particular alloy, as shown by the following table.

| Alloy and temper | $\frac{\text{Height of drop (spot-welded)}}{\text{Height of drop (riveted)}}$ (percent) |
|---|---|
| Alclad 24S-T3 | 65 |
| Alclad 24S-T3 aged to -T81 after assembly | 51 |
| Alclad 24S-T36 | 91 |
| Alclad 75S-T6 | 73 |
| Alclad 24S-T81 | 61 |
| Alclad 24S-T86 | 68 |
| Alclad 14S-T6 | 79 |

The ratios varied from 51 percent for Alclad 24S-T3 aged to -T81 after assembly to 91 percent for Alclad 24S-T36, with an average value of about 70 percent.

The Alclad 24S-T36 beams proved to be the most consistent in impact both from the standpoint of height of drop causing failure in each riveted and each spot-welded beam and from the standpoint of average height of drop causing failure in riveted beams compared with that in spot-welded beams. The radiographic analyses showed that the spots through which failure occurred in these beams (table VI) were in the best condition of all the beams tested in impact. The low ratio of drop producing failure of spot-welded beams to that producing failure of riveted beams, 51 percent, for Alclad 24S-T3 aged to -T81 after assembly again emphasizes the fact that no beneficial results seem to obtain from aging to -T81 after assembly.

Figure 14 shows that the Alclad 75S-T6 riveted beams exhibited the greatest resistance to failure in impact and the Alclad 24S-T3 beams proved to be the least satisfactory of the riveted beams. Of the spot-welded beams, those of Alclad 24S-T36 proved to be best in resistance to impact and those of Alclad 24S-T3 aged to -T81 after assembly were the least satisfactory.

It is seen in figure 14 that the riveted beams line up according to the height of drop producing failure very nearly in the same order as the tensile strengths of the materials of which the beams were made. Alclad 24S-T81 beams were the outstanding exceptions to this order in that they exhibited the third highest resistance to impact, whereas the material from which the beams were made showed the next to lowest tensile strength. The order of failure of spot-welded beams in impact did not agree very well with the order of the tensile strengths of the material although a trend is observable in that the three alloys of highest tensile strength are the three highest in point of resistance to impact. As in the case of the riveted beams, the spot-welded beams lined up almost exactly in the same order according to resistance to impact as they did according to ultimate loads in the static tests.

Figure 14 shows no particular correlation between the toughness value of the material and the height of drop producing failure, in either the riveted or spot-welded beams. The Alclad 24S-T3 beams are a notable example in that, even though the material exhibited the greatest toughness value, the riveted beams were least satisfactory in impact and the spot-welded beams were next to the least satisfactory. This lack of correlation is significant because it indicates that the relative impact resistance of built-up members cannot be predicted from the mechanical properties of the material. The absence of correlation is not surprising because it is known that the effect of stress-raisers, such as rivet holes or spot welds, on the tensile strength and elongation varies considerably with different materials.

It should be emphasized that because of the nature of the impact tests described herein, in which successive drops were made from increasing heights, the maximum height of drop is not a direct measure of the energy required to produce rupture. It is probable that, had single drop tests been employed, the alloys might have lined up somewhat differently according to height of drop producing failure. However, single drop tests require a large number of specimens, with the type of equipment available for measuring the amount of energy to produce rupture.

The repeated drop tests, moreover, do represent some types of conditions which exist in actual service. In interpreting, analyzing, and applying the results of these tests, the limitations thereof should be considered.

## SUMMARY OF RESULTS

The results of the static and impact tests of built-up beams of various high-strength aluminum alloys employing riveted and spot-welded connections may be summarized as follows:

1. Mechanical-property determinations of the material used in the channels and bottom cover plates showed that, except for Alclad 24S-T3 aged to -T81 after assembly, the properties of the materials exceeded ANC design mechanical properties about 3 to 19 percent.

2. Static shear tests of spot-welded joints of the various materials used and of the rivets used in connecting the bottom cover plate showed that the average load per rivet or per spot weld exceeded the ANC design shear load (by about 9 percent for rivets and about 48 to 99 percent for spot welds), indicating that the connections in the beams represented acceptable production practice.

3. The static shear tests of the spot-welded joints revealed a wide range of values of load per spot which were not consistent with the presence or absence in the welds of cracks, porosity, or expulsion, as revealed by radiographic examination before testing.

4. The failures encountered in the static and impact beam tests occurred in the bottom cover plates through the rivet holes or spot welds. Neither the rivets nor the spot welds sheared. The fractures were of the shear type in which the plane of fracture was at an angle of about 45° to the plane of the sheet. All the beams failed in the region of theoretical maximum stress, or, in several cases, at the rivets or spots immediately adjacent.

5. Computed elastic strains based on the maximum bending moment under the load points, using primary-modulus values for the Alclad materials, agreed well with strains measured by means of electric strain gages.

6. The average measured deflection of the riveted beams, within the elastic range, was about 12 percent higher than the computed deflection, and the measured deflection of the spot-welded beams was about 10 percent higher than the computed deflection, when the secondary-modulus values of the materials were used in the computations. The difference would have been greater if primary-modulus values had been used.

7. In the static beam tests, the average ultimate load of all the spot-welded beams was about 12 percent less than that of the riveted beams. The greatest difference, about 22 percent, was for beams of Alclad 24S-T3 aged to -T81 after assembly.

8. In the static beam tests, the modulus of failure of the riveted beams of all alloys agreed with the tensile strength of the material within 4 percent except in the case of Alclad 24S-T3 for which the modulus of failure was about 12 percent lower than the tensile strength. For the spot-welded beams, the modulus of failure was about 25 percent lower than the tensile strength for beams of Alclad 24S-T3 and Alclad 24S-T3 aged to -T81 after assembly. The average for the beams of all other alloys was about 10 percent lower than the tensile strength.

9. The maximum deflection before rupture in the static tests of riveted beams was about 1.3 inches for Alclad 24S-T3, Alclad 24S-T3 aged to -T81 after assembly, and Alclad 75S-T6. The average for all the other beams was about 15 percent less. The deflection before rupture of the spot-welded beams ranged from 1.0 inch for Alclad 75S-T6 to 0.7 inch for Alclad 24S-T3.

10. In all alloys the riveted beams were better than the spot-welded beams in resistance to impact. The average ratio of maximum height of drop for the spot-welded beams to maximum height of drop for the riveted beams was about 70 percent. The greatest difference was in the case of Alclad 24S-T3 aged to -T81 after assembly, where the ratio was 51 percent. The least difference was for Alclad 24S-T36 beams, where the ratio was 91 percent.

11. The heights of drop producing failure in the impact tests of the riveted beams were nearly in the same order as the tensile strengths of the materials in the beams. This was not true for the spot-welded beams although a trend was observable in that the three alloys of highest tensile strength were the three highest in resistance to impact.

12. No particular correlation could be observed between the toughness value of the material and the height of drop producing failure in either the riveted or spot-welded beams.

## CONCLUSIONS

The following general conclusions may be drawn from the static and impact tests of riveted and spot-welded beams of various high-strength aluminum alloys. The beams of this investigation were spot-welded before present aircraft specifications for structural welding became effective. It is evident from radiographic analyses that the soundness of the spot welds does not meet the present aircraft specifications for structural welding. In interpreting the conclusions, the nature of the impact tests should be considered.

1. For static loads on riveted beams, the values of modulus of failure were about the same as the tensile strengths for all alloys except Alclad 24S-T3, for which the modulus of failure was about 12 percent lower than the tensile strength.

2. For static loads on spot-welded beams, the values of modulus of failure were about 10 percent lower than the tensile strengths for Alclad 24S-T81, Alclad 24S-T36, Alclad 24S-T86, Alclad 14S-T6, and Alclad 75S-T6 and about 25 percent lower for Alclad 24S-T3 and Alclad 24S-T3 aged to -T81 after assembly.

3. In general, beams of highest-strength materials had the greatest resistance to impact. Of the riveted beams, Alclad 75S-T6 required the highest drop and Alclad 24S-T3 the lowest. Of the spot-welded beams, Alclad 24S-T36 required the highest drop and Alclad 24S-T3 aged to -T81 after assembly the lowest.

4. The height of drop producing failure of the spot-welded beams averaged about 70 percent of that producing failure of the riveted beams.

5. No direct relationship seems to exist between the toughness value of the material as determined from the tensile properties and relative ability to resist impact of the material in the form of a riveted or welded structure.

6. Aging of beams of Alclad 24S-T3 to -T81 after assembly is certainly not advantageous and probably undesirable, at least for spot-welded beams, from the standpoint of static and impact strength.

Aluminum Research Laboratories
Aluminum Company of America
New Kensington, Pa., May 6, 1948

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TABLE I

MECHANICAL PROPERTIES OF MATERIAL USED IN FABRICATION OF BEAMS[1]

[Tests were made in with-grain direction]

| Alloy and temper | Tensile strength (psi) | | Yield strength (0.2 percent set) (psi) (2) | | Elongation in 2 in. (percent) | Toughness (in.-lb/in.$^3$) (3) |
|---|---|---|---|---|---|---|
| | A (4) | B (5) | A (4) | B (5) | A (4) | |
| Alclad 24S-T3 | 69,700 | 63,000 | 54,900 | 46,000 | 19.8 | 12,300 |
| Alclad 24S-T3 aged to -T81 after assembly[6] | 66,400 | 67,000 | 56,650 | 59,000 | 7.1 | 4,400 |
| Alclad 24S-T36 | 71,900 | 67,000 | 61,950 | 58,000 | 15.1 | 10,100 |
| Alclad 75S-T6 | 80,500 | 73,000 | 72,000 | 65,000 | 12.7 | 9,700 |
| Alclad 24S-T81 | 68,700 | 67,000 | 61,100 | 59,000 | 7.0 | 4,500 |
| Alclad 24S-T86 | 75,500 | 72,000 | 71,600 | 69,000 | 6.6 | 4,800 |
| Alclad 14S-T6 | 70,700 | 65,000 | 64,500 | 58,000 | 10.1 | 6,800 |

[1]Standard tension test specimens for sheet metals were used; fig. 2 of reference 3.
[2]Strains measured with electrical extensometer (Templin type).
[3]Toughness = $\frac{\text{Tensile strength + yield strength}}{2} \times$ elongation.
[4]A, mechanical properties, with grain, of material used in beams.
[5]B, design mechanical properties, with grain, based on minimum guaranteed tensile properties. From reference 1.
[6]Specimens were cut from ends of beams.

TABLE II

SHEAR STRENGTHS OF RIVETS AND SPOT WELDS

[All failures were by shearing of rivet or spot weld]

| Alloy and temper of plate material | Type of connection | Ultimate load per rivet or spot (lb) | | | A (2) | Average shear strength (psi) (3) | B (psi) (4) |
|---|---|---|---|---|---|---|---|
| | | Minimum | Average (1) | Maximum | | | |
| Alclad 24S-T3 | Spot welds | 885 | 988 | 1080 | 552 | ------ | ------ |
| Alclad 24S-T36 | Spot welds | 875 | 993 | 1070 | 552 | ------ | ------ |
| Alclad 75S-T6 | Spot welds | 1015 | 1098 | 1175 | 552 | ------ | ------ |
| Alclad 24S-T81 | Spot welds | 710 | 900 | 1080 | 552 | ------ | ------ |
| Alclad 24S-T86 | Spot welds | 765 | 958 | 1165 | 552 | ------ | ------ |
| Alclad 14S-T6 | Spot welds | 525 | 813 | 1030 | 552 | ------ | ------ |
| Alclad 24S-T3 | 1/8-in. 24S-T31 rivets | 569 | 578 | 589 | 531 | 44,650 | 41,000 |

[1]Average of eight panels for Alclad 24S-T3, four panels for all others.
[2]A, design shear load per spot or rivet from reference 1.
[3]Based on area of two holes: $\frac{\pi}{4} \times (0.1285)^2 \times 2 = 0.0259$ in.$^2$.
[4]B, design shear strength of driven rivets from reference 1.

TABLE III

AVERAGE ULTIMATE SHEAR LOADS PER SPOT AND RADIOGRAPHIC ANALYSES OF SPOT-WELDED PANELS

[Analyses made by Physical Metallurgy Division]

| Specimen designation | Alloy | Average ultimate shear load per spot (lb) (1) | Analyses |
|---|---|---|---|
| 75982-1 | Alclad 24S-T3 | 965 | Both spot welds appeared to be sound |
| 75982-2 | Alclad 24S-T3 | 1027 | Both welds were cracked in the center of the nuggets |
| 75982-3 | Alclad 24S-T3 | 1000 | One weld was cracked in the center of the nugget; the other weld appeared to be sound |
| 75982-4 | Alclad 24S-T3 | 977 | One weld was cracked in the center of the nugget; the other weld appeared to be sound |
| 75982-5 | Alclad 24S-T3 | 922 | One weld was cracked in the center of the nugget; the other weld appeared to be sound |
| 75982-6 | Alclad 24S-T3 | 1057 | Both welds appeared to be sound |
| 75982-7 | Alclad 24S-T3 | 1002 | One weld contained cracks in the center of the nugget; the other weld contained expulsion |
| 75982-8 | Alclad 24S-T3 | 957 | One weld was cracked; the other weld appeared to be sound |
| 75983-1 | Alclad 24S-T36 | 985 | One weld was cracked in the center of the nugget; the other appeared to be sound |
| 75983-2 | Alclad 24S-T36 | 1060 | Both welds were cracked in the center of each nugget |
| 75983-3 | Alclad 24S-T36 | 1005 | Both welds appeared to be sound |
| 75983-4 | Alclad 24S-T36 | 922 | One weld was cracked; the other appeared to be sound |
| 75984-1 | Alclad 75S-T6 | 1107 | Both welds appeared to be sound |
| 75984-2 | Alclad 75S-T6 | 1095 | Both welds appeared to be sound |
| 75984-3 | Alclad 75S-T6 | 1097 | One weld contained cracks in the center of the nugget; two of the welds appeared to be sound |
| 75984-4 | Alclad 75S-T6 | 1093 | All three welds contained small cracks in the center of the welds |
| 75990-1 | Alclad 24S-T81 | 1022 | One weld contained cracks in the center of the nugget; the other two welds appeared to be sound |
| 75990-2 | Alclad 24S-T81 | 860 | Both welds contained numerous cracks, porosity, and expulsion |
| 75990-3 | Alclad 24S-T81 | 757 | All three welds contained numerous cracks, porosity, and expulsion |
| 75990-4 | Alclad 24S-T81 | 960 | One weld was cracked; the other appeared to be sound |
| 75991-1 | Alclad-24S-T86 | 913 | All three welds contained numerous cracks, porosity, and expulsion |
| 75991-2 | Alclad-24S-T86 | 1065 | All three welds contained cracks; one also contained expulsion |
| 75991-3 | Alclad 24S-T86 | 832 | Two of the welds contained numerous cracks, porosity, and expulsion; one weld appeared to be sound |
| 75991-4 | Alclad 24S-T86 | 1023 | One weld was cracked; the other two appeared to be sound |
| 80558-1 | Alclad 14S-T6 | 970 | All three welds appeared to be sound |
| 80558-2 | Alclad 14S-T6 | 558 | All three welds appeared to be sound |
| 80558-3 | Alclad 14S-T6 | 760 | All three welds appeared to be sound |
| 80558-4 | Alclad 14S-T6 | 962 | All three welds appeared to be sound |

[1]Panels contained two or three spot welds. The welds were tested individually.

TABLE IV

RADIOGRAPHIC ANALYSES OF SPOT-WELDED BEAMS

[Analyses made by Physical Metallurgy Division]

| Specimen designation (1) | Alloy and temper | Analyses |
|---|---|---|
| | | Static test specimens |
| 75982-7-A | Alclad 24S-T3 | All but two welds were cracked and most of them also contained expulsion |
| 75982-7-B | Alclad 24S-T3 | All but three welds were cracked and most of them also contained expulsion |
| 75982-6-A | Alclad 24S-T3 | The majority of the welds were cracked; 16 of the welds also contained expulsion |
| 75982-6-B | Alclad 24S-T3 | About three-fourths of the welds contained cracks and expulsion |
| 75982-2-A | Alclad 24S-T3 aged to -T81 after assembly | Fifteen of the welds were badly cracked and contained expulsion; seven welds contained very small cracks |
| 75982-2-B | Alclad 24S-T3 aged to -T81 after assembly | Eleven of the welds were badly cracked and contained expulsion; nine of the welds contained very small cracks |
| 75982-1-A | Alclad 24S-T3 aged to -T81 after assembly | The majority of the welds were cracked |
| 75982-1-B | Alclad 24S-T3 aged to -T81 after assembly | The majority of the welds were cracked |
| 75983-3-A | Alclad 24S-T36 | About one-fourth of the welds contained very small cracks; four welds contained severe cracks and expulsion |
| 75983-3-B | Alclad 24S-T36 | About three-fourths of the welds were cracked and contained expulsion |
| 75983-1-A | Alclad 24S-T36 | About one-third of the welds contained very small cracks and two of them also contained expulsion |
| 75983-1-B | Alclad 24S-T36 | About one-third of the welds contained very small cracks; three welds contained severe cracks and expulsion |
| 75984-1-A | Alclad 75S-T6 | About one-half of the welds contained cracks and most of these also contained expulsion |
| 75984-1-B | Alclad 75S-T6 | About one-third of the welds contained cracks and most of these also contained expulsion |
| 75984-2-A | Alclad 75S-T6 | About one-fourth of the welds contained cracks and expulsion |
| 75984-2-B | Alclad 75S-T6 | About one-fourth of the welds contained cracks and several of them also contained expulsion |
| 75990-4-A | Alclad 24S-T81 | Almost all the welds contained severe cracks, porosity, and expulsion |
| 75990-4-B | Alclad 24S-T81 | Almost all the welds were cracked; the majority of these contained severe cracks, porosity, and expulsion |
| 75990-3-A | Alclad 24S-T81 | Almost all the welds contained cracks, 15 of which contained severe cracks, porosity, and expulsion |
| 75990-3-B | Alclad 24S-T81 | Almost all the welds were cracked; 16 of these contained severe cracks, porosity, and expulsion |
| 75991-4-A | Alclad 24S-T86 | About one-half of the welds were cracked; one-fourth of these contained severe cracks, porosity, and expulsion |
| 75991-4-B | Alclad 24S-T86 | About one-half of the welds contained very small cracks; 17 welds contained severe cracks, porosity, and expulsion |
| 75991-2-A | Alclad 24S-T86 | The majority of the welds were badly cracked and contained expulsion |
| 75991-2-B | Alclad 24S-T86 | The majority of the welds were badly cracked and contained expulsion |
| 80558-1-A | Alclad 14S-T6 | About one-fourth of the welds were cracked; several of these contained severe cracks and expulsion |
| 80558-1-B | Alclad 14S-T6 | About three-fourths of the welds were cracked; 14 of these contained severe cracks and expulsion |
| 80558-3-A | Alclad 14S-T6 | Three welds contained cracks; the remainder of the welds appeared to be sound |
| 80558-3-B | Alclad 14S-T6 | Two welds contained cracks; the remainder of the welds appeared to be sound |

[1]A and B identify the two flanges of the beam.

TABLE IV - Concluded

RADIOGRAPHIC ANALYSES OF SPOT-WELDED BEAMS

| Specimen designation (1) | Alloy and temper | Analyses |
|---|---|---|
| Impact test specimens | | |
| 75982-8-A | Alclad 24S-T3 | Fourteen of the spot welds contained cracks in the centers of the nuggets, five of which also contained expulsion; the remainder of the welds appeared to be sound |
| 75982-8-B | Alclad 24S-T3 | Twenty-seven of the welds contained cracks, four of which also contained expulsion; the remainder of the welds appeared to be sound |
| 75982-5-A | Alclad 24S-T3 | Most of the welds contained small cracks with the exception of 5 which were badly cracked; 20 of the welds also contained expulsion |
| 75982-5-B | Alclad 24S-T3 | The majority of the welds contained cracks, 8 of which were badly cracked; 20 of the welds also contained expulsion |
| 75982-4-A | Alclad 24S-T3 aged to -T81 after assembly | All the welds contained small cracks with the exception of 4 which were badly cracked; 10 of the welds also contained expulsion |
| 75982-4-B | Alclad 24S-T3 aged to -T81 after assembly | Most of the welds contained small cracks with the exception of 10 which were badly cracked; 9 of the welds also contained expulsion |
| 75983-3-A | Alclad 24S-T3 aged to -T81 after assembly | The majority of the welds were cracked and contained expulsion |
| 75983-3-B | Alclad 24S-T3 aged to -T81 after assembly | The majority of the welds were cracked and contained expulsion |
| 75983-2-A | Alclad 24S-T36 | Four of the welds contained very small cracks; two welds contained severe cracks and expulsion |
| 75983-2-B | Alclad 24S-T36 | Seven of the welds contained very small cracks; two of the welds contained severe cracks and several welds contained expulsion |
| 75983-4-A | Alclad 24S-T36 | Eleven of the welds contained cracks and expulsion; the remainder of the welds appeared to be sound |
| 75983-4-B | Alclad 24S-T36 | Nine of the welds contained cracks, three of which contained a large amount of cracks and expulsion; three other welds contained expulsion and the remainder appeared to be sound |
| 75984-3-A | Alclad 75S-T6 | Three of the welds contained cracks; the remainder of the welds appeared to be sound |
| 75984-3-B | Alclad 75S-T6 | Five of the welds contained small cracks; one was severely cracked and contained expulsion |
| 75984-4-A | Alclad 75S-T6 | Almost all of the welds contained a very small crack in the center of each nugget |
| 75984-4-B | Alclad 75S-T6 | Twelve of the welds contained a very small crack in the center of each nugget and one of the welds contained numerous cracks |
| 75990-2-A | Alclad 24S-T81 | Sixteen of the welds contained numerous cracks, porosity, and expulsion; five of the welds contained a very small crack in the center of each nugget |
| 75990-2-B | Alclad 24S-T81 | Twenty-two of the welds contained numerous cracks, porosity, and expulsion; seven of the welds contained a very small crack in the center of each nugget |
| 75990-1-A | Alclad 24S-T81 | About one-third of the welds contained small cracks; nine welds contained severe cracks, porosity, and expulsion |
| 75990-1-B | Alclad 24S-T81 | About one-third of the welds contained small cracks; eight of the welds contained severe cracks and expulsion |
| 75991-1-A | Alclad 24S-T86 | All of the welds contained numerous cracks, porosity, and expulsion |
| 75991-1-B | Alclad 24S-T86 | All of the welds contained numerous cracks, porosity, and expulsion |
| 75991-3-A | Alclad 24S-T86 | About one-third of the welds were cracked; 10 of these contained severe cracks, porosity, and expulsion |
| 75991-3-B | Alclad 24S-T86 | About two-thirds of the welds contained small cracks; three welds contained severe cracks, porosity, and expulsion |
| 80558-2-A | Alclad 14S-T6 | Six of the welds contained cracks; three welds contained severe cracks and expulsion |
| 80558-2-B | Alclad 14S-T6 | About one-third of the welds contained cracks and expulsion |
| 80558-4-A | Alclad 14S-T6 | Most of the welds contained severe cracks and some of them also contained expulsion |
| 80558-4-B | Alclad 14S-T6 | Eight of the welds contained cracks and expulsion |

[1]A and B identify the two flanges of the beam.

TABLE V

RESULTS OF STATIC AND IMPACT TESTS OF RIVETED AND SPOT-WELDED BEAMS

| | | Static test | | | | | Impact test | | |
|---|---|---|---|---|---|---|---|---|---|
| Alloy and temper | Type of connection | Specimen designation | Ultimate load (lb) | Modulus of failure (psi) (1) | Total deflection at rupture (in.) (2) | Rivet hole or spot weld through which failure occurred (3) | Specimen designation | Height of drop at failure (in.) | Rivet hole or spot weld through which failure occurred (3) |
| Alclad 24S-T3 | Riveted | 75982-7 | 5500 | 63,100 | 1.43 | 26, 27 | 75982-6 | 9.5 | 26, 27 |
| Alclad 24S-T3 | Riveted | 75982-5 | 5230 | 60,000 | 1.21 | 26 | 75982-8 | 9.0 | 28 |
| | | | Av. 5365 | 61,550 | 1.32 | | | Av. 9.3 | |
| Alclad 24S-T3 | Spot-welded | 75982-7 | 4710 | 54,100 | .66 | 18 | 75982-8 | 6.0 | 18 |
| Alclad 24S-T3 | Spot-welded | 75982-6 | 4365 | 50,100 | .80 | 18 | 75982-5 | 6.0 | 20 |
| | | | Av. 4538 | 52,100 | .73 | | | Av. 6.0 | |
| Alclad 24S-T3 aged to -T81 after assembly | Riveted | 75982-1-T81 | 5660 | 65,000 | 1.17 | 27 | 75982-2-T81 | 10.5 | 28 |
| Alclad 24S-T3 aged to -T81 after assembly | Riveted | 75982-4-T81 | 5620 | 64,500 | 1.44 | 28 | 75982-3-T81 | 11.0 | 28 |
| | | | Av. 5640 | 64,750 | 1.30 | | | Av. 10.8 | |
| Alclad 24S-T3 aged to -T81 after assembly | Spot-welded | 75982-2-T81 | 4450 | 51,100 | .65 | 19 | 75982-4-T81 | 7.0 | 20 |
| Alclad 24S-T3 aged to -T81 after assembly | Spot-welded | 75982-1-T81 | 4370 | 50,200 | .65 | 19 | 75982-3-T81 | 4.0 | 21 |
| | | | Av. 4410 | 50,650 | .65 | | | Av. 5.5 | |
| Alclad 24S-T36 | Riveted | 75983-2 | 6253 | 71,800 | 1.05 | 27 | 75983-4 | 11.5 | 28 |
| Alclad 24S-T36 | Riveted | 75983-1 | 6525 | 74,900 | 1.29 | 26 | 75983-3 | 11.5 | 25 |
| | | | Av. 6389 | 73,350 | 1.17 | | | Av. 11.5 | |
| Alclad 24S-T36 | Spot-welded | 75983-3 | 5680 | 65,200 | .99 | 18 | 75983-2 | 10.5 | 19 |
| Alclad 24S-T36 | Spot-welded | 75983-1 | 6095 | 70,000 | .90 | 20 | 75983-4 | 10.5 | 19 |
| | | | Av. 5888 | 67,600 | .94 | | | Av. 10.5 | |
| Alclad 75S-T6 | Riveted | 75984-2 | 7000 | 80,400 | 1.28 | 27, 28 | 75984-3 | 13.0 | 27 |
| Alclad 75S-T6 | Riveted | 75984-1 | 7115 | 81,700 | 1.39 | 27, 28 | 75984-4 | 14.0 | 29 |
| | | | Av. 7058 | 81,050 | 1.34 | | | Av. 13.5 | |
| Alclad 75S-T6 | Spot-welded | 75984-1 | 6360 | 73,000 | .99 | 19 | 75984-3 | 9.5 | 17 |
| Alclad 75S-T6 | Spot-welded | 75984-2 | 6250 | 71,800 | 1.02 | 18 | 75984-4 | 10.0 | 20 |
| | | | Av. 6305 | 72,400 | 1.00 | | | Av. 9.8 | |
| Alclad 24S-T81 | Riveted | 75990-2 | 5783 | 66,400 | 1.00 | 28 | 75990-4 | 12.0 | 28 |
| Alclad 24S-T81 | Riveted | 75990-3 | 6210 | 71,300 | 1.17 | 28 | | | |
| | | | Av. 5997 | 68,850 | 1.08 | | | | |
| Alclad 24S-T81 | Spot-welded | 75990-4 | 4430 | 50,900 | .84 | 20 | 75990-2 | 6.0 | 18 |
| Alclad 24S-T81 | Spot-welded | 75990-3 | 5950 | 68,300 | .62 | 19 | 75990-1 | 8.5 | 18 |
| | | | Av. 5190 | 59,600 | .73 | | | Av. 7.3 | |
| Alclad 24S-T86 | Riveted | 75991-3 | 6500 | 74,600 | 1.12 | 28 | 75991-2 | 13.0 | 28 |
| Alclad 24S-T86 | Riveted | 75991-4 | 6590 | 75,700 | 1.14 | 28 | | | |
| | | | Av. 6545 | 75,150 | 1.13 | | | | |
| Alclad 24S-T86 | Spot-welded | 75991-4 | 6090 | 69,900 | .82 | 18 | 75991-1 | 8.0 | 19 |
| Alclad 24S-T86 | Spot-welded | 75991-2 | 5742 | 65,900 | .95 | 18 | 75991-3 | 9.5 | 18 |
| | | | Av. 5916 | 67,900 | .88 | | | Av. 8.8 | |
| Alclad 14S-T6 | Riveted | 80558-2 | 5962 | 68,400 | 1.17 | 26 | 80558-4 | 10.5 | 26 |
| Alclad 14S-T6 | Riveted | 80558-1 | 5910 | 67,800 | 1.19 | 28 | 80558-3 | 11.0 | 28 |
| | | | Av. 5936 | 68,100 | 1118 | | | Av. 10.8 | |
| Alclad 14S-T6 | Spot-welded | 80558-1 | 5400 | 62,000 | .91 | 17 | 80558-2 | 9.5 | 20 |
| Alclad 14S-T6 | Spot-welded | 80558-3 | 5680 | 65,200 | .89 | 20 | 80558-4 | 7.5 | 21 |
| | | | Av. 5540 | 63,600 | .90 | | | Av. 8.5 | |

[1]Obtained from beam formula, Stress = $\frac{Mc}{I}$. Stress is calculated at edge of 4-in. bearing block so that following expression results: Modulus of failure = $\frac{\frac{P}{2}(24 - 2) \times 1.91}{1.83} = 11.48P$, where P is ultimate load.

[2]From Amsler diagram.

[3]Rivet 28 is at center of beam. Spot 19 is at center of beam.

TABLE VI

RADIOGRAPHIC ANALYSES OF SPOT WELDS THROUGH WHICH FAILURE OCCURRED

[Analyses made by Physical Metallurgy Division]

| Specimen designation | Alloy and temper | Location of failure (1) | Analyses of spots through which failure occurred | |
|---|---|---|---|---|
| | | | Flange A | Flange B |
| Static tests | | | | |
| 75982-7 | Alclad 24S-T3 | 18 | Very small crack | Severe cracks, expulsion |
| 75982-6 | Alclad 24S-T3 | 18 | Expulsion | Severe cracks, expulsion |
| 75982-2-T81 | Alclad 24S-T3 aged to -T81 after assembly | 19 | Cracks, expulsion | Severe cracks, expulsion |
| 75982-1-T81 | Alclad 24S-T3 aged to -T81 after assembly | 19 | Sound | Severe cracks, expulsion |
| 75983-3 | Alclad 24S-T36 | 18 | A probable very small crack | Severe cracks, expulsion |
| 75983-1 | Alclad 24S-T36 | 20 | Sound | Sound |
| 75984-1 | Alclad 75S-T6 | 19 | Sound | Very small crack, expulsion |
| 75984-2 | Alclad 75S-T6 | 18 | Sound | Very small crack |
| 75990-4 | Alclad 24S-T81 | 20 | Very small crack | Cracks, expulsion |
| 75990-3 | Alclad 24S-T81 | 19 | Very small crack | Very small crack |
| 75991-4 | Alclad 24S-T86 | 18 | Sound | Very small crack |
| 75991-2 | Alclad 24S-T86 | 18 | Small cracks, expulsion | Small crack, expulsion |
| 80558-1 | Alclad 14S-T6 | 17 | Sound | Severe cracks, expulsion |
| 80558-3 | Alclad 14S-T6 | 20 | Sound | Sound |
| Impact tests | | | | |
| 75982-8 | Alclad 24S-T3 | 18 | Very small crack | Very small crack |
| 75982-5 | Alclad 24S-T3 | 20 | Sound | Severe cracks, expulsion |
| 75982-4-T81 | Alclad 24S-T3 aged to -T81 after assembly | 20 | Severe cracks, expulsion | Very small cracks |
| 75982-3-T81 | Alclad 24S-T3 aged to T81 after assembly | 21 | Cracks | Very badly cracked, porosity, expulsion |
| 75983-2 | Alclad 24S-T36 | 19 | Sound | Small crack |
| 75983-4 | Alclad 24S-T36 | 19 | Sound | Small crack, expulsion |
| 75984-3 | Alclad 75S-T6 | 17 | Severe cracks | Sound |
| 75984-4 | Alclad 75S-T6 | 20 | Small crack | Sound |
| 75990-2 | Alclad 24S-T81 | 18 | Severe cracks, porosity, expulsion | Severe cracks, porosity, expulsion |
| 75990-1 | Alclad 24S-T81 | 18 | Small crack | Sound |
| 75991-1 | Alclad 24S-T86 | 19 | Severe cracks, porosity, expulsion | Cracks, expulsion |
| 75991-3 | Alclad 24S-T86 | 18 | Severe cracks, porosity expulsion | Small crack |
| 80558-2 | Alclad 14S-T6 | 20 | Small crack | Sound |
| 80558-4 | Alclad 14S-T6 | 21 | Cracks, expulsion | Sound |

[1]Spot weld 19 is at center of beam.

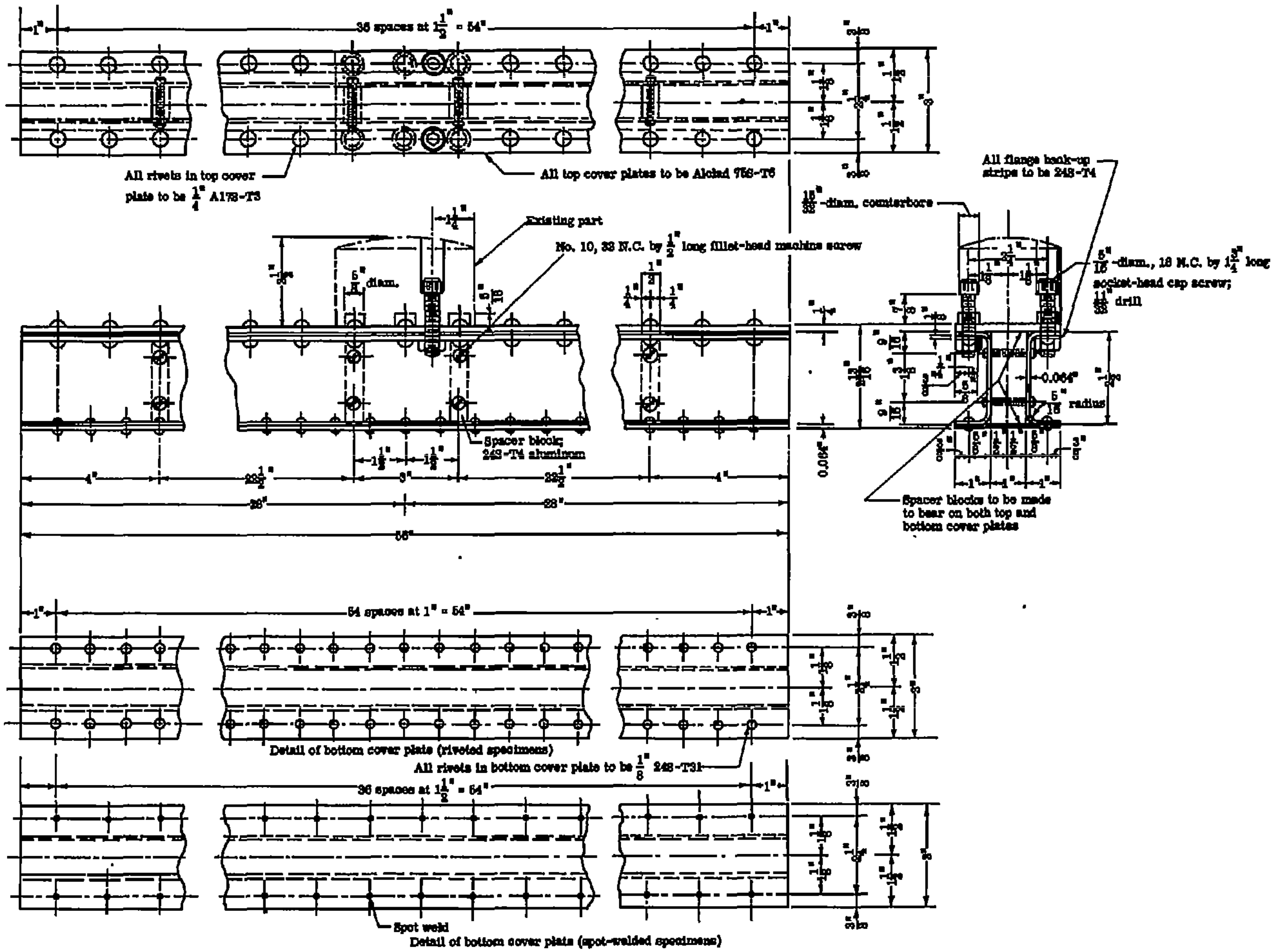


Figure 1.- Beam specimen for static and impact tests.

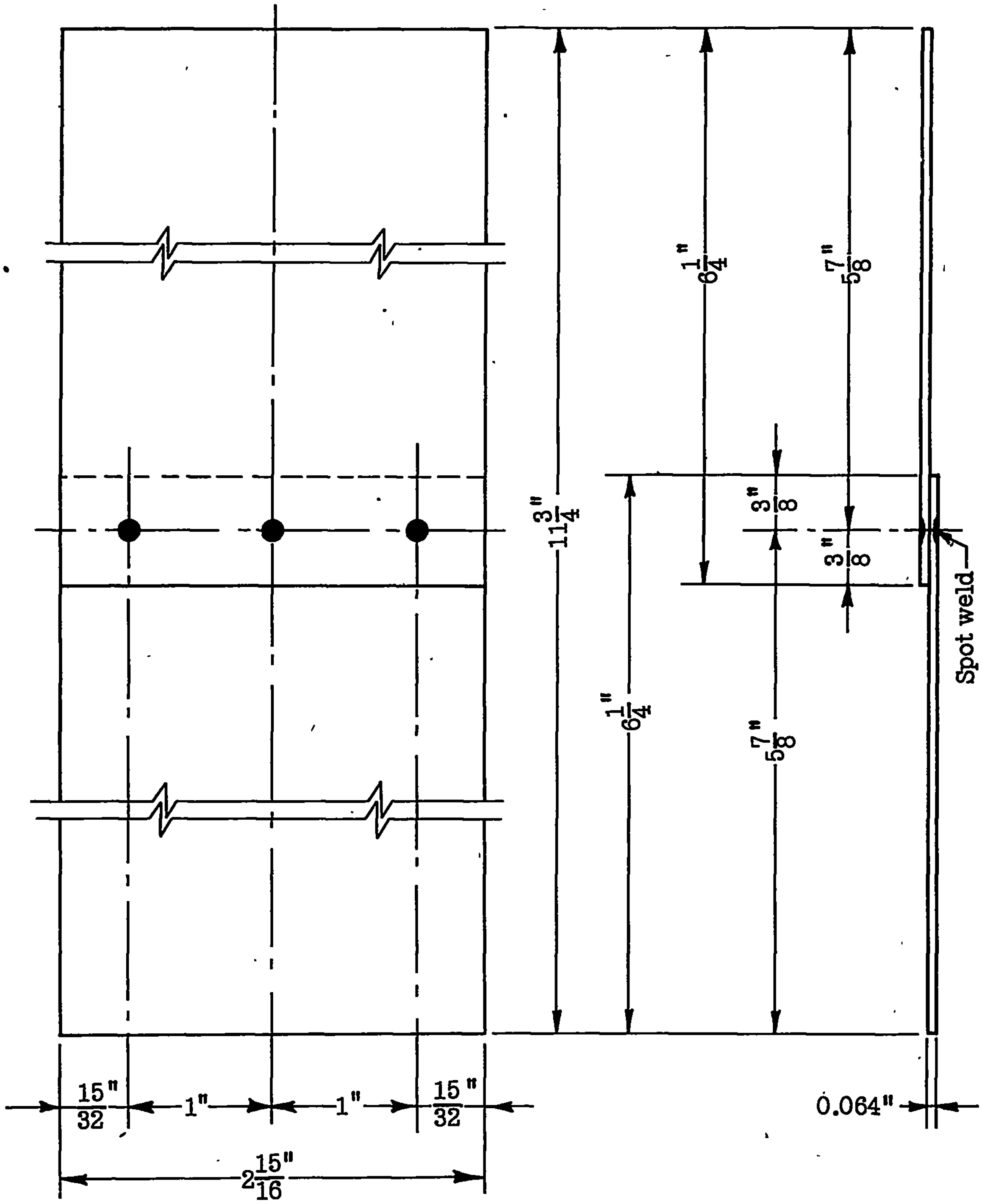


Figure 2.- Panel for static tests of spot-welded joints.

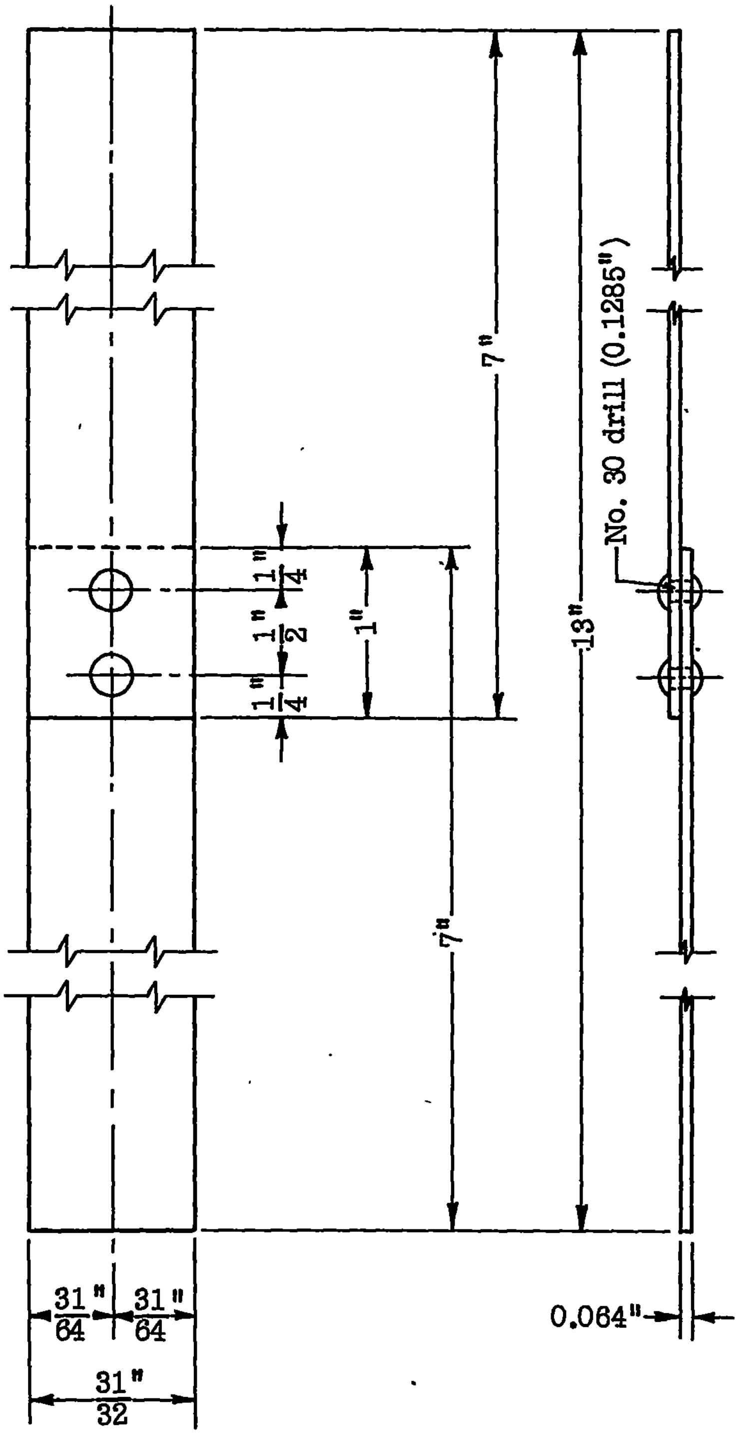


Figure 3.- Shear specimen for $\frac{1}{8}$-inch-diameter rivets.

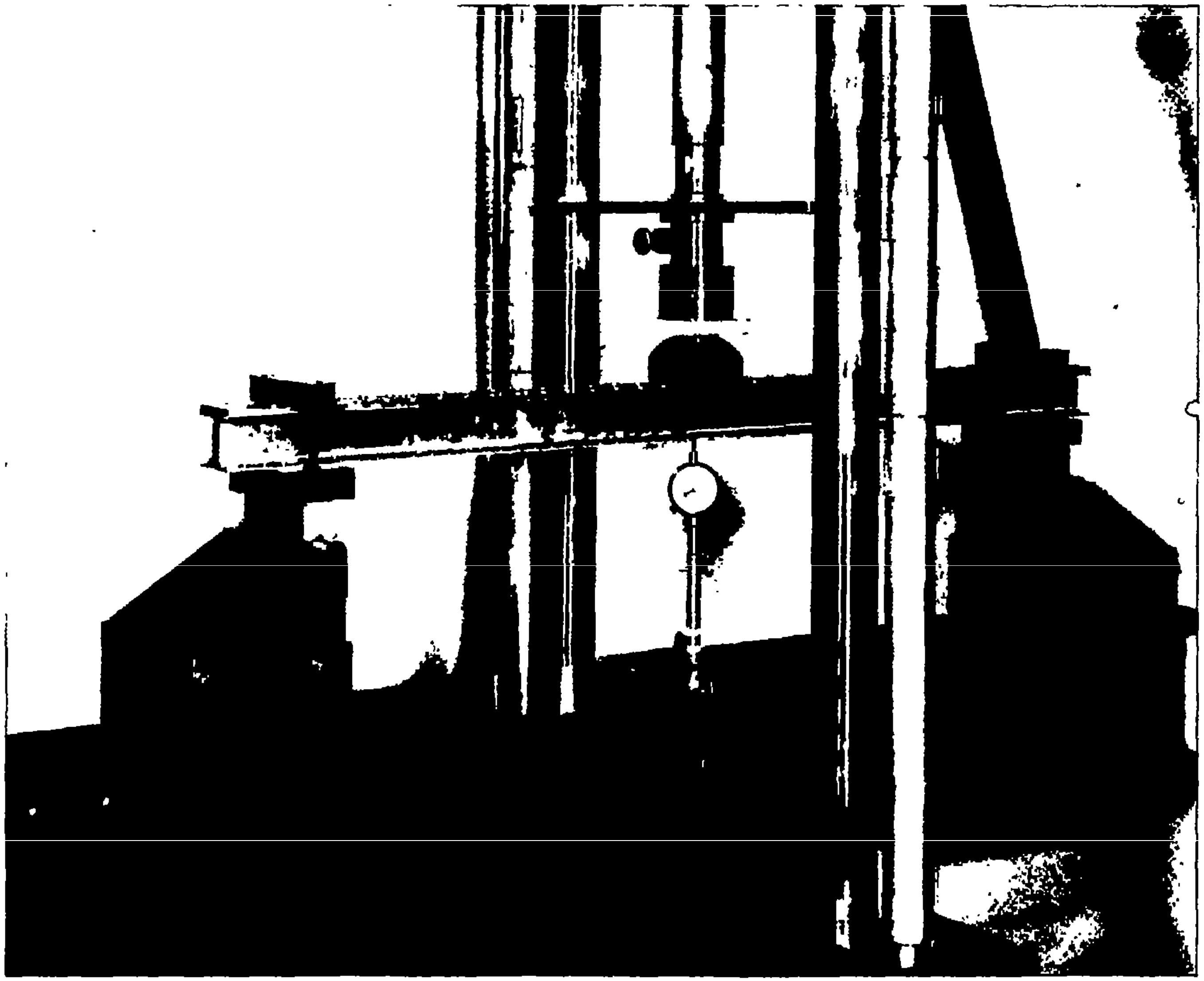

Figure 4.- Arrangement for static beam test.

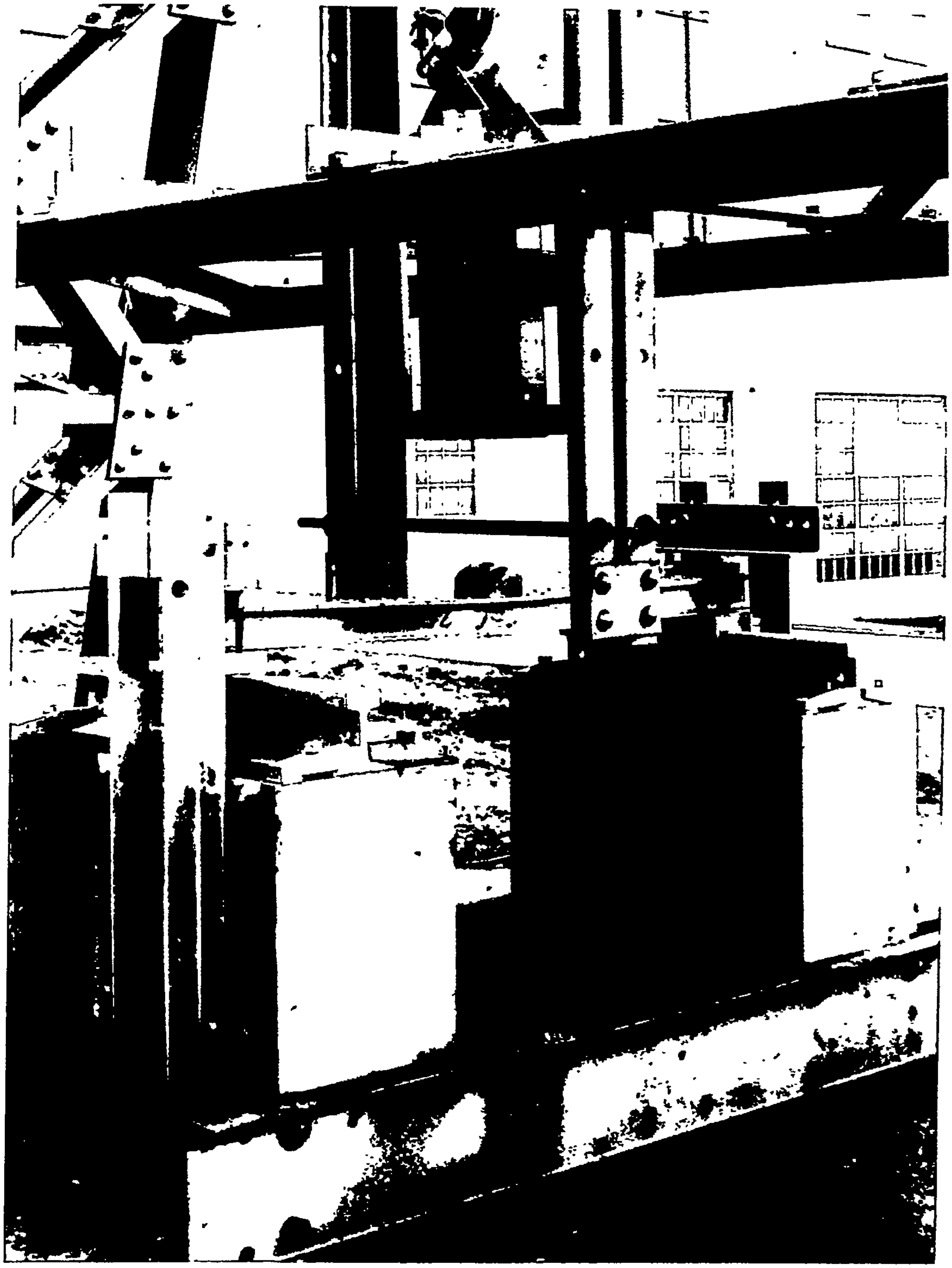

Figure 5.- Arrangement for impact beam test.

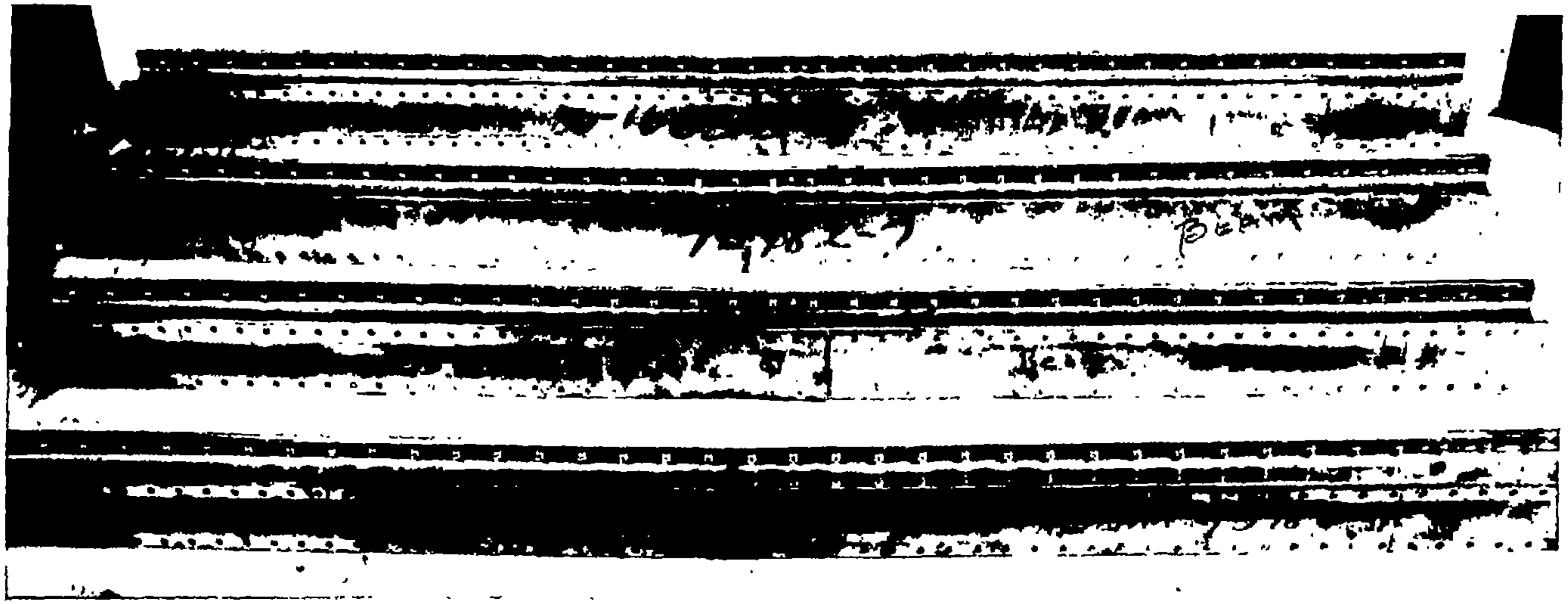

Figure 6.- Typical failures of riveted static beam specimens.

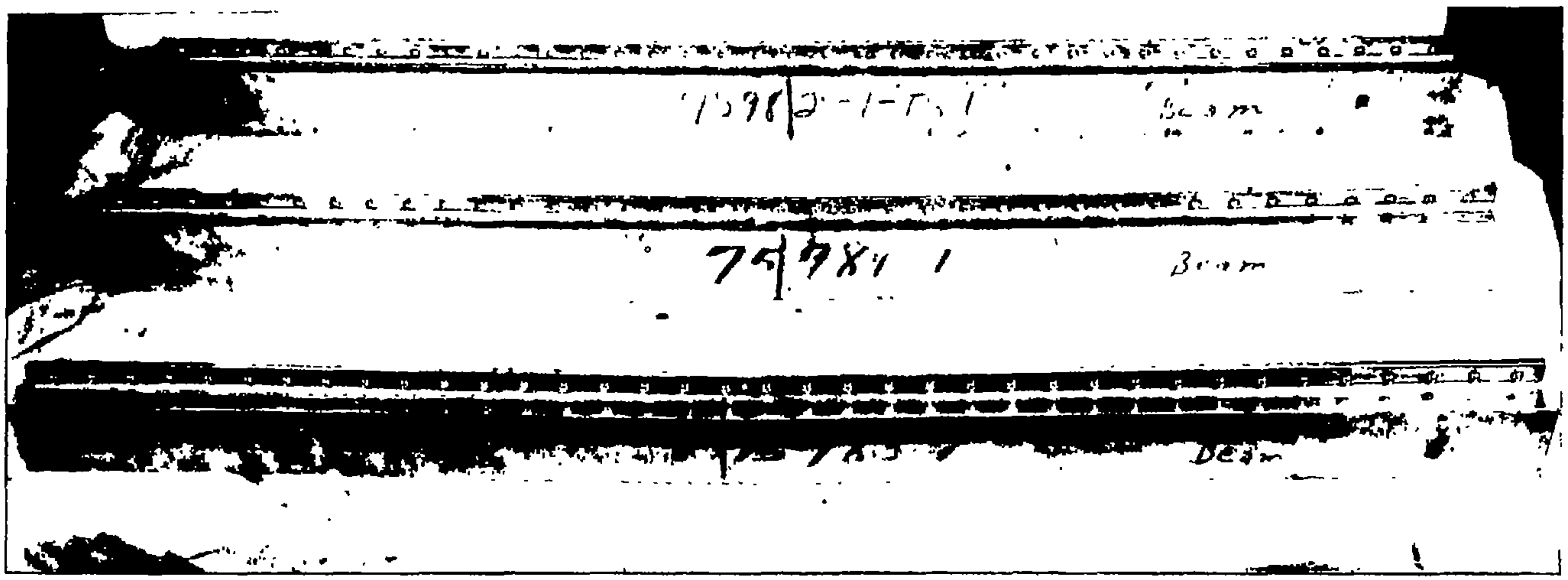

Figure 7.- Typical failures of spot-welded static beam specimens.

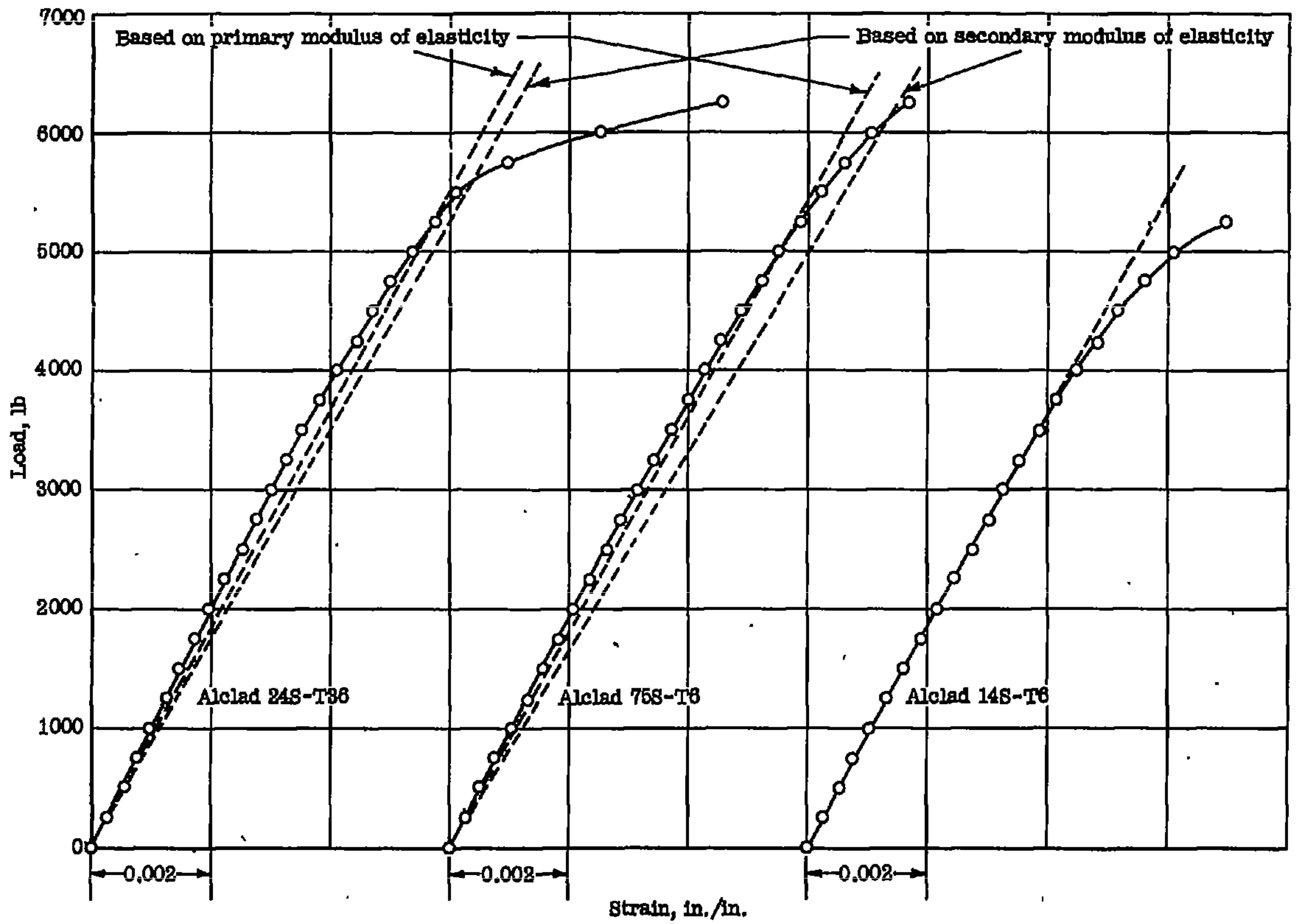


Figure 8.- Load-strain curves of static beam tests of riveted beams. Dashed lines represent computed values of strain. Strain = $\frac{\text{Stress}}{E} = \frac{Mc}{EI}$. Plotted strains measured with SR-4 electrical strain gages.

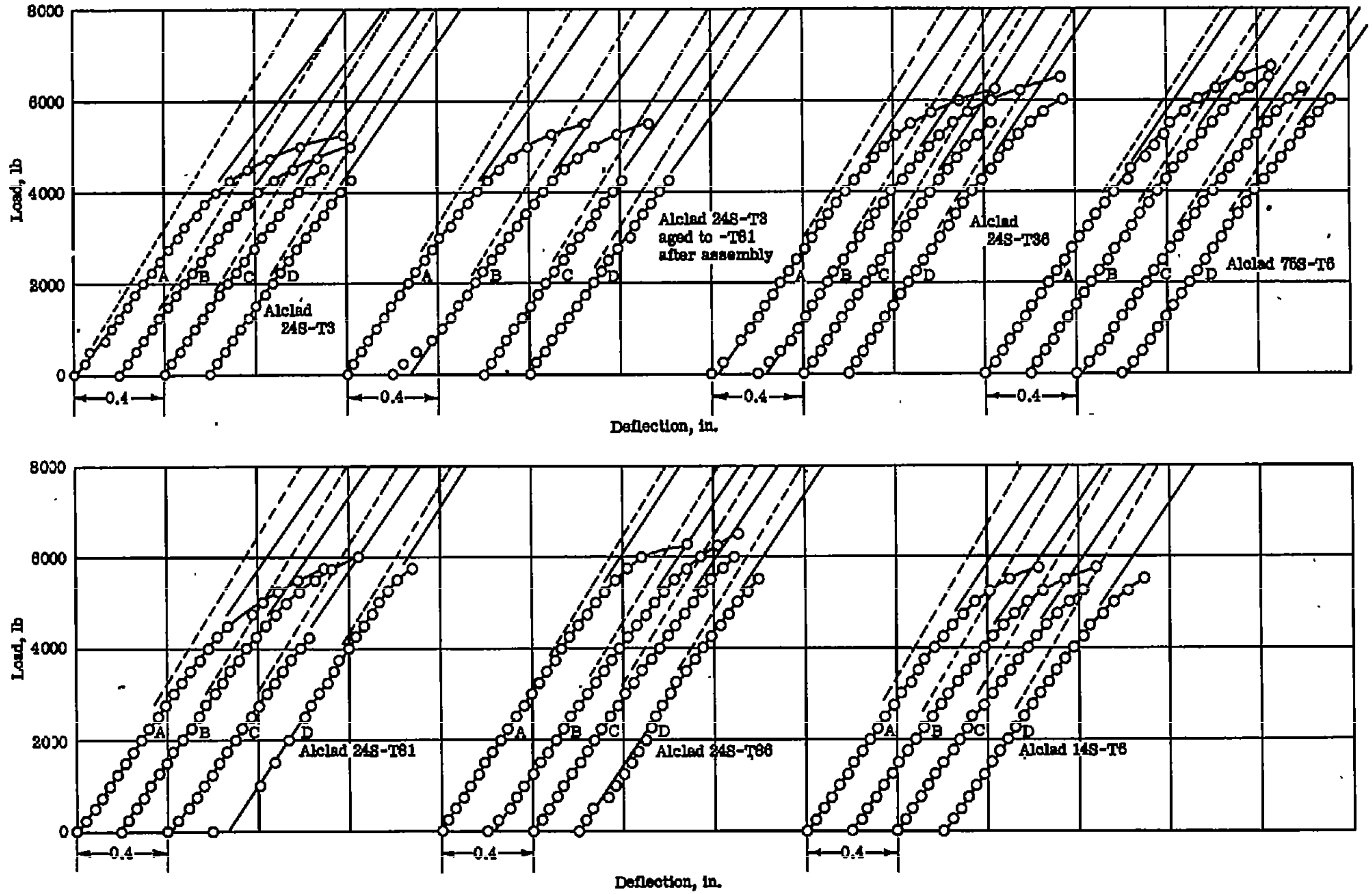


Figure 9.- Charts of load against deflection for static tests of riveted and spot-welded beams. Computed deflections are shown by dashed lines. Beams were loaded at center of 4-foot span. A and B, riveted; C and D, spot-welded.

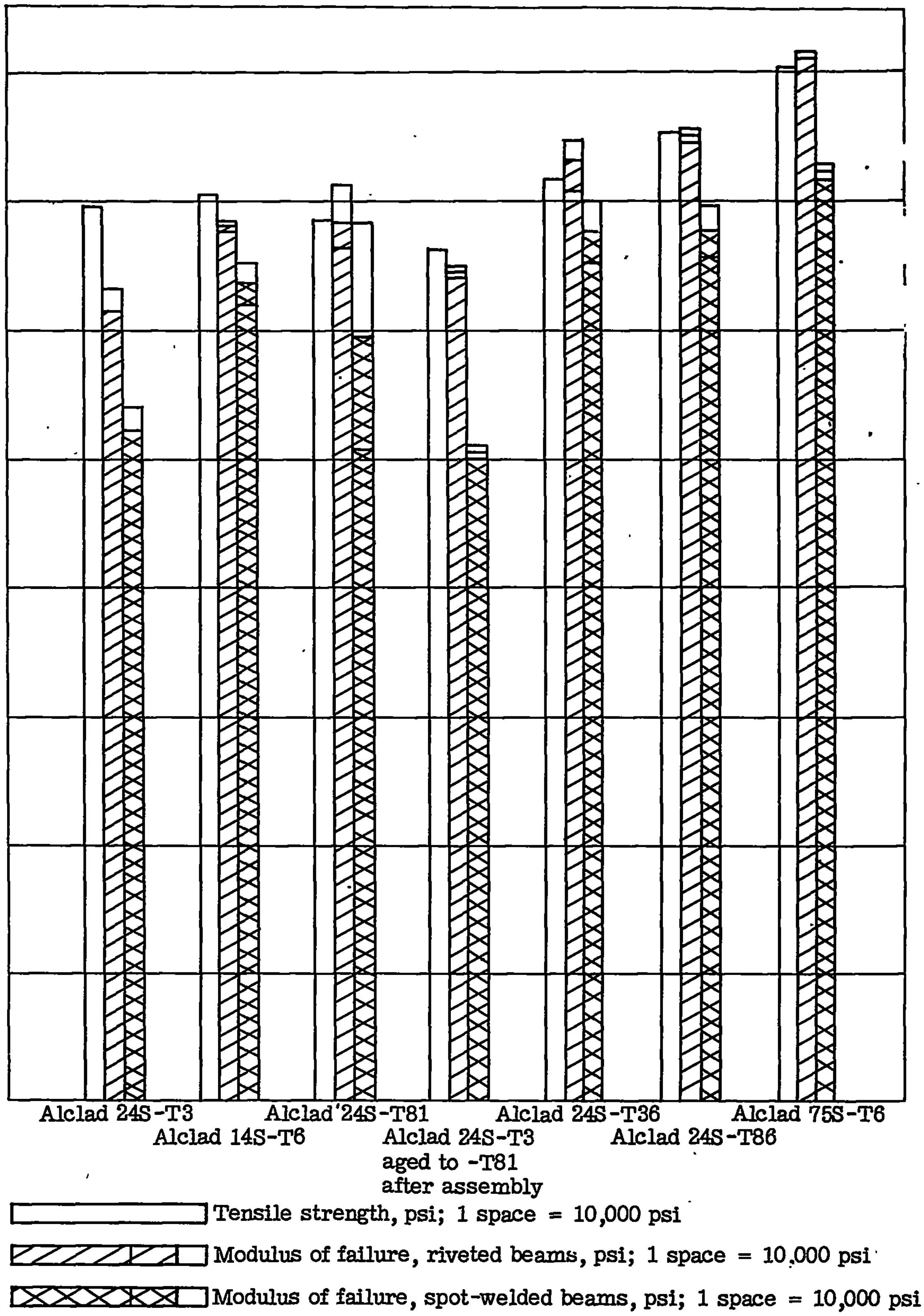


Figure 10.- Comparison of tensile strength of material and modulus of failure statically.

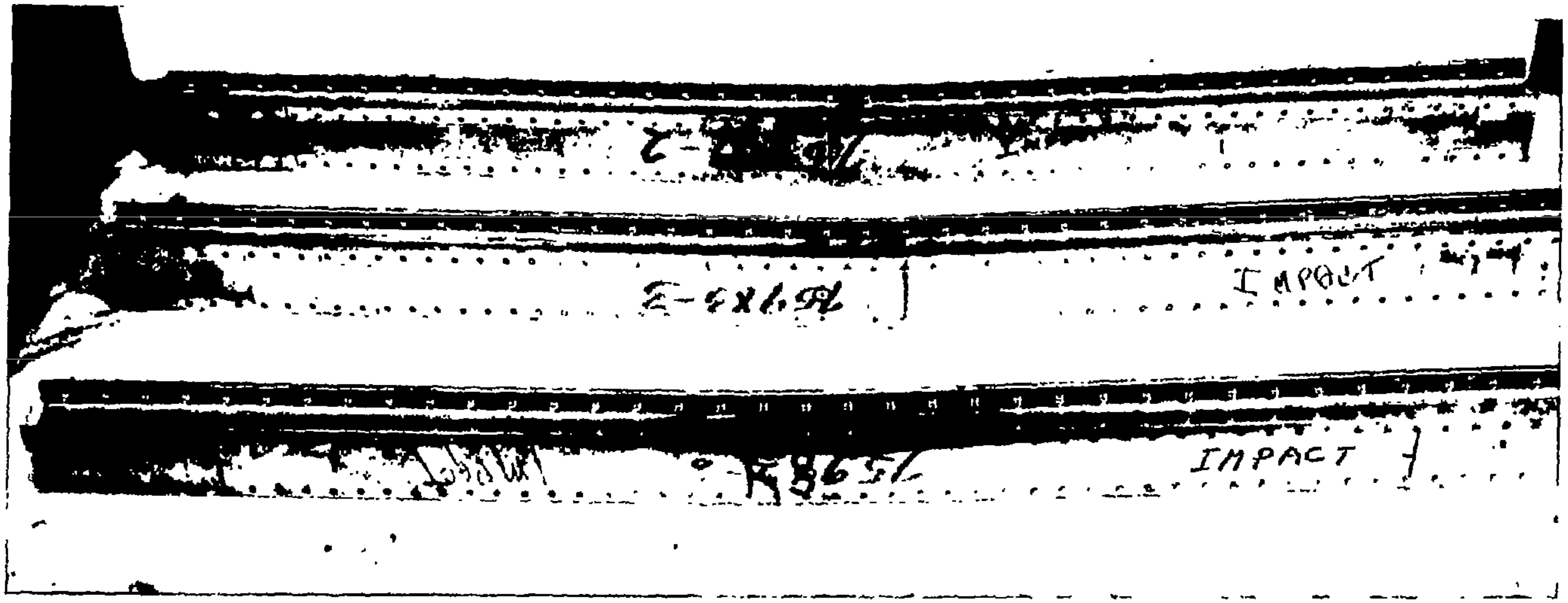


Figure 11.- Typical failures of riveted impact beam specimens.

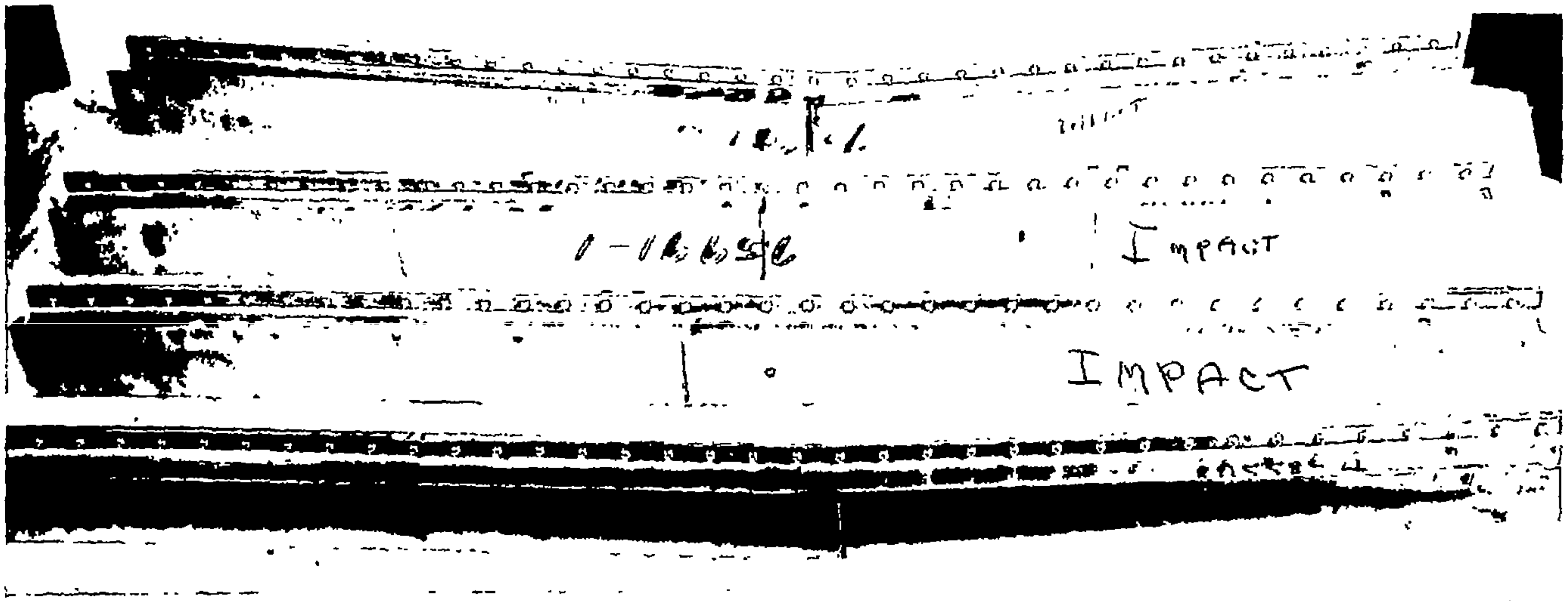


Figure 12.- Typical failures of spot-welded impact beam specimens.

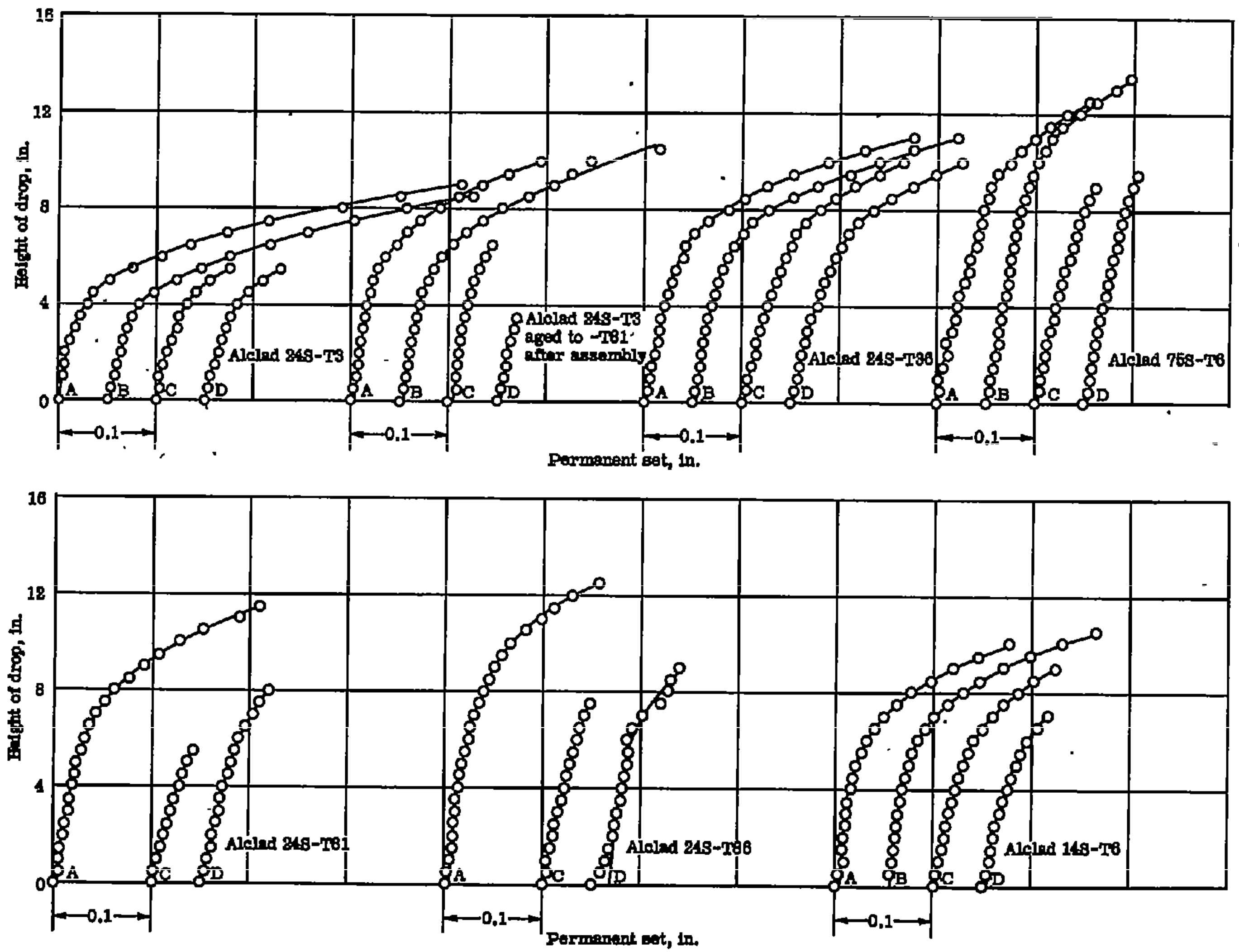


Figure 13.- Curves of height of drop against permanent set for impact tests of riveted and spot-welded beams. 250-pound tup dropped on beam at center of 4-foot span. A and B, riveted beams; C and D, spot-welded beams.

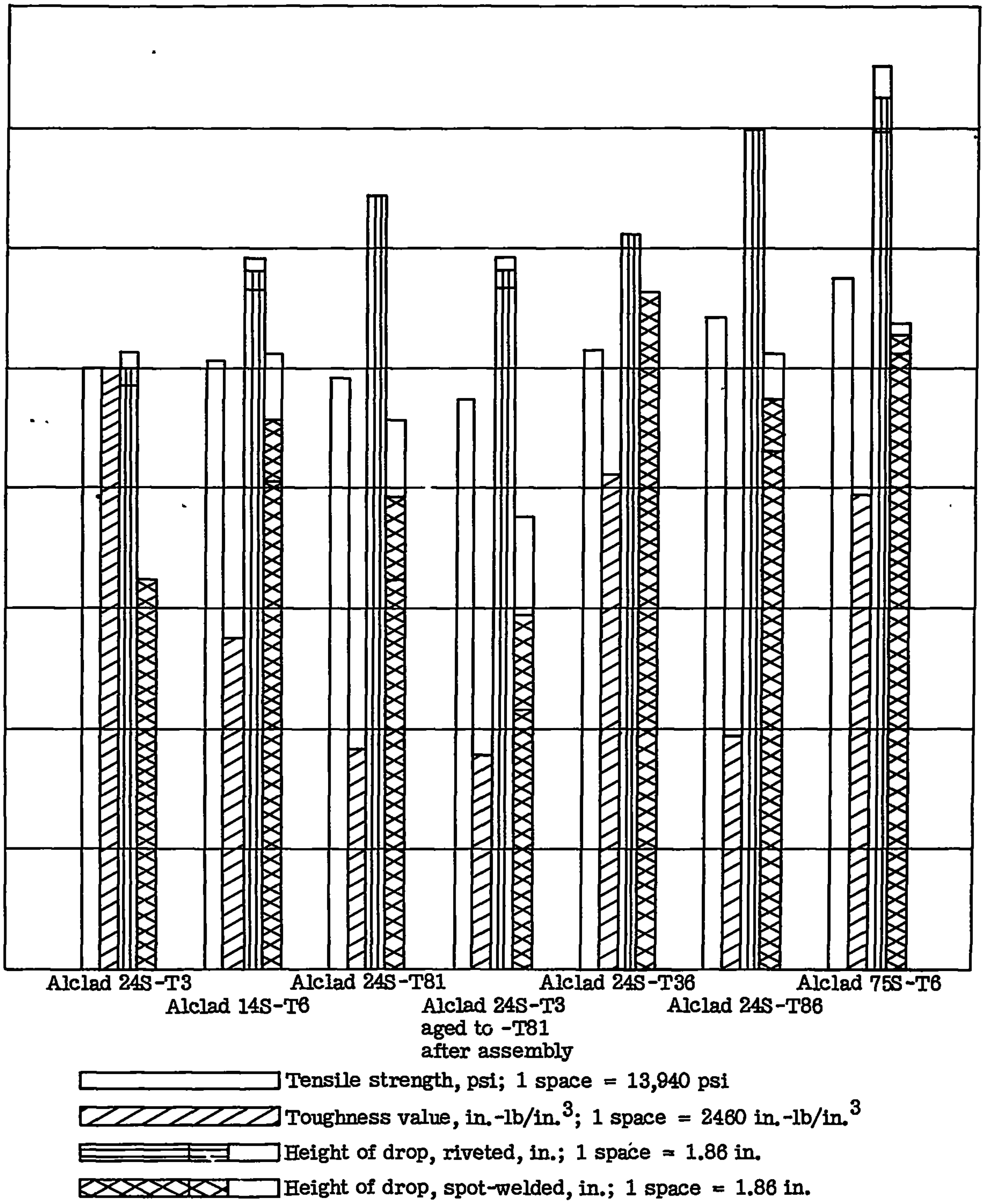


Figure 14.- Comparison of tensile strength of material, toughness value, and height of drop causing failure in impact.

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